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II. *A Series of Observations on, and a Discovery of, the Period of the Variation of the Light of the Star marked δ by Bayer, near the Head of Cepheus. In a Letter from John Goodricke, Esq. to Nevil Maskelyne, D. D. F. R. S. and Astronomer Royal.*

Read November 24, 1785.

s i r,

York, June 28, 1785.

THE improvements which of late years have been introduced into astronomy, should be attributed not only to the diligence and accuracy wherewith astronomers prosecute their observations and discoveries, but in part also to your exertions, and especially to that kind encouragement which you have, on many occasions, afforded those who make this science their chief study; and I am happy to have this opportunity of acknowledging myself one of those who are much indebted to you in this respect. Under these impressions I thought I could not do better than to address to you the following account of a periodical variation in the star δ Cephei, which I lately discovered. This account will, I presume, be a considerable addition to the few discoveries that have but very lately been made respecting the same subject. They may probably lead to some better knowledge of the fixed stars, especially of their constitution and the cause of their remarkable changes.

My

My first observation was Oct. 19, 1784; and as I wished to establish the several points of the variation with as great accuracy as the nature of the subject will admit of, I have delayed sending this account till now; but as observations made through so long an interval of time must be very numerous, and would only swell this paper to an unnecessary length, I have in the following series formed a selection, chiefly of those that were made under the most favourable circumstances; and I must add, that none of those that are omitted contradict the results. From this series I have settled, that the star has a periodical variation of 5 d. 8 h. $37\frac{1}{2}$, during which time it undergoes the following changes:

1. It is at its greatest brightness about one day and thirteen hours.
2. Its diminution is performed in about one day and eighteen hours.
3. It is at its greatest obscuration about one day and twelve hours.
4. It increases in about thirteen hours.

When it is in the first point it appears as a star of between the fourth and third magnitude; but its relative brightness does not seem always to be quite the same, being sometimes between ζ and ι Cephei, and sometimes only equal to, or something less than, ι Cephei, or between ζ Cephei and γ Lacertæ. In the third point it appears as a star of between the fourth and fifth magnitude, if not nearer the fifth; and its relative brightness is as follows: *nearly* equal to ϵ and ξ Cephei, and considerably less than γ Lacertæ.

The relative brightness and magnitude of those stars to which the variable one was compared, is as follows: ζ Cephei, the brightest, is between the third and fourth magnitude; ι Cephei,

the next brightest, is between the fourth and third; γ Lacertæ is less than ι Cephei, and of about the fourth magnitude; ϵ Cephei is between the fourth and fifth magnitude; and ξ Cephei, which is a little less than ϵ , is between the fifth and fourth.

A Series of Observations on the Variation of the Light of the Star δ Cephei.

1784, Oct. 19, at $8\frac{1}{2}$ h. I thought it was rather less than ζ Cephei.

Oct. 20, at $8\frac{1}{2}$ h. it was rather less than ζ , and about equal to ι Cephei.

Oct. 22, at $9\frac{1}{2}$ h. less than ι , and larger than ϵ Cephei; but the air was not very favourable.

Oct. 23, at $6\frac{1}{2}$ h. and 11 h. less than γ Lacertæ, and a little brighter than ϵ Cephei.

Oct. 24, at $6\frac{1}{2}$ h. less than ζ Cephei, somewhat less than ι Cephei, and something brighter than γ Lacertæ; strong moon-light, and air rather hazy.

At $8\frac{1}{2}$ h. to 11 h. a little less than ζ and ι Cephei, and brighter than γ Lacertæ; air clear and frosty; the moon was very low at 11 h.

Oct. 25, at 6 h. 8 h. and 11 h. nearly the same; air pretty clear, and moon bright.

Oct. 26, at $9\frac{1}{2}$ h. and 11 h. rather less than γ Lacertæ; strong moon-light, but air very clear.

Oct. 27, $6\frac{1}{4}$ h. and $10\frac{1}{2}$ h. less than γ Lacertæ, and brighter than ϵ Cephei; ditto.

Oct. 28, at $9\frac{1}{2}$ h. and 12 h. just the same, if not less; moon-light, but the air was remarkably clear.

Oct. 31, at 8 h. nearly equal to, if not less than, γ Lacertæ.

Nov. 1, at $11\frac{1}{2}$ h. somewhat less than γ Lacertæ; air clear.

Nov. 3, at $12\frac{1}{2}$ h. equal to, if not a little less than, γ Lacertæ; but the weather was not very favourable: it seemed to have increased since my first observation, which was at $5\frac{1}{2}$ h.

Nov. 5, at 13 h. brighter than γ Lacertæ, and less than ζ Cephei; flying clouds, but air pretty clear.

Nov. 6, at 9 h. and $12\frac{1}{2}$ h. rather less than γ Lacertæ.

Nov. 7, at $7\frac{1}{2}$ h. I thought it still rather less than γ Lacertæ, but at $10\frac{1}{2}$ h. and 11 h. it was evidently less than it; air clear.

Nov. 10, at 11 h. and $12\frac{1}{2}$ h. something less than ζ Cephei, and brighter than γ Lacertæ; clear sky.

Nov. 11, at 7 h. to 12 h. a little brighter than γ Lacertæ.

Nov. 12, at 7 h. and $8\frac{1}{2}$ h. about equal to γ Lacertæ. From $9\frac{1}{2}$ h. to $12\frac{1}{2}$ h. it was something less than γ Lacertæ, and brighter than ϵ Cephei.

Nov. 13, at $6\frac{1}{2}$ h. to 11 h. only a little brighter than ϵ Cephei, though sometimes it appeared equal to it.

Nov. 14, at $7\frac{1}{4}$ h. brighter than ϵ Cephei, and, I believe, equal to γ Lacertæ. There was a haze about γ Lacertæ.

Nov. 15, at 12 h. less than ζ Cephei, and brighter than γ Lacertæ; fine *aurora borealis*, but the air was very clear.

At $18\frac{1}{2}$ h. ditto; but the air was not very clear.

Nov. 16, at $6\frac{1}{2}$ h. and 10 h. just the same, if not decreased at 10 h.

Nov. 17, at $6\frac{1}{4}$ h. to $10\frac{1}{2}$ h. a little less than γ Lacertæ, and brighter than ϵ Cephei; air clear.

Nov. 18, at 9 h. to 12 h. and 19 h. little brighter than ϵ and ζ Cephei.

Nov. 19, at 6 h. to 10 h. just the same, being but a very little brighter than ϵ and ζ Cephei; air clear.

At $18\frac{1}{2}$ h. it was increased, being now brighter than ϵ and ζ Cephei.

Nov. 20, 7 h. to 11 h. considerably brighter than γ Lacertæ, something less than ζ Cephei; air extremely clear at 11 h.

Nov. 21, at 6 h. exactly the same.

Nov. 22, at $9\frac{1}{4}$ h. about equal to γ Lacertæ; moon-light.

Nov. 25, at 7 h. and 8 h. less than γ Lacertæ, and brighter than ϵ and ζ Cephei; air clear.

At $9\frac{1}{2}$ h. and $9\frac{3}{4}$ h. a little brighter than γ Lacertæ.

At $10\frac{1}{2}$ h. and 12 h. brighter than γ Lacertæ, and about between ζ Cephei and γ Lacertæ, but rather nearer γ Lacertæ; air clear and moon-light.

Nov. 26, at 9 h. exactly as last night.

Nov. 29, at $7\frac{1}{2}$ and 8 h. less than γ Lacertæ, and something brighter than ϵ and ζ Cephei.

Nov. 30, at $8\frac{1}{4}$ h. as last night; air clear.

At $10\frac{1}{4}$ h. between γ Lacertæ and ϵ Cephei, but nearer ϵ .

At $10\frac{1}{2}$ h. 11 h. and 12 h. ditto, but nearer γ Lacertæ; air clear. I have no doubt of its increase since $8\frac{1}{4}$ h. Mr. E. PIGOTT found it rather less than ζ Cephei at $18\frac{1}{2}$ h. See his Observations.

Dec. 1, 11 h. something less than ζ Cephei, and brighter than γ Lacertæ..

Dec. 3, $12\frac{1}{4}$ h. less than γ Lacertæ, and brighter than ϵ Cephei.

Dec. 4, $5\frac{1}{2}$ h. to 12 h. little brighter than ϵ and ζ Cephei.

Dec. 7, 10 h. and 11 h. between ζ Cephei and γ Lacertæ.

Dec. 8, at $10\frac{1}{2}$ h. between γ Lacertæ and ϵ Cephei.

Dec.

Dec. 9, $11\frac{1}{2}$ h. ditto, but nearer ϵ Cephei; about equal to ξ Cephei.

Dec. 11, 6 h. something less than γ Lacertæ; brighter than ϵ Cephei.

At $7\frac{1}{2}$ h. something brighter than γ Lacertæ.

At $8\frac{1}{4}$ h. brighter than γ Lacertæ.

At 9 h. and 11 h. between ζ Cephei and γ Lacertæ, but nearer γ Lacertæ.

Dec. 12, at 6 h. something less than ζ Cephei.

Dec. 13, at $9\frac{1}{4}$ h. brighter than γ Lacertæ; considerably less than ζ Cephei.

Dec. 14, at $8\frac{1}{2}$ h. nearly equal to, if not less than, γ Lacertæ.

Dec. 17, at $5\frac{1}{2}$ h. and $7\frac{1}{2}$ h. equal to, if not less than, ϵ Cephei, and between ζ Cephei and γ Lacertæ, but nearer ζ .

Dec. 18, at 9 h. less than ϵ Cephei, and between ζ Cephei and γ Lacertæ, but nearer γ Lacertæ.

Dec. 19, at 19 h. less than γ Lacertæ; considerably brighter than ϵ and ξ Cephei.

Dec. 20, at 6 h. and 7 h. about equal to ξ Cephei, and a little brighter than ϵ Cephei.

Dec. 21, at 8 h. and 18 h. nearly equal to ϵ Cephei.

Dec. 22, at $8\frac{1}{2}$ h. considerably brighter than γ Lacertæ, less than ζ , and a little less than ϵ Cephei; strong moon-light.

Dec. 25, at $5\frac{1}{2}$ h. between γ Lacertæ and ϵ Cephei.

Dec. 28, at 8 h. &c. between ζ Cephei and γ Lacertæ, and equal to, if not less than, ϵ Cephei.

Having, in the beginning of this paper, mentioned my intention of omitting several observations, in order to be as short as possible, I have thought it best, with the exception of one only, to leave out all that were made in January, February, and

and March, because they were much interrupted by the then unfavourable state of the weather.

1785, Feb. 8, at 9 h. equal to γ Lacertæ; considerably less than ι Cephei.

At 10 h. rather brighter than γ Lacertæ.

At 11 h. brighter than γ Lacertæ; a little less than ι Cephei.

April 1, at 11 h. about equal to ϵ and ξ Cephei; weather not favourable.

April 2, at $12\frac{1}{2}$ h. ditto.

April 3, at 8 h. a little less than ι Cephei, less than ζ Cephei, and brighter than γ Lacertæ.

April 4, at 12 h. ditto; if any thing, it is less than it was last night.

April 7, at 10 h. about equal to ϵ and ξ Cephei; but the weather was not very favourable.

April 8, at $7\frac{1}{2}$ h. considerably less than ι Cephei, brighter than ϵ and ξ Cephei; but the air was not very clear.

At 10 h. it was increased.

At 11 h. only a little less than ι Cephei.

At 12 h. equal to, if not a little brighter than ι , and less than ζ Cephei; considerably brighter than γ Lacertæ.

April 12, at 12 h. a little less than ϵ , and nearly equal to ξ Cephei.

April 13, at 9 h. just the same.

At 11 h. seemed rather increased, being equal to ϵ , and a little brighter than ξ Cephei.

April 16, at $11\frac{1}{2}$ h. nearly equal to ϵ and ξ Cephei.

April 17, at 9 h. and 11 h. rather a little less than ϵ , and a little brighter than ξ Cephei.

April

April 19, at 11½ h. about equal to, Cephei, if not a little brighter than it; less than ζ Cephei, and considerably brighter than γ Lacertæ.

April 24, at 10 h. a little brighter than γ Lacertæ; considerably less than, Cephei.

At 12 h. scarce at all altered, but if any thing it is a little increased; air very clear, and observation good.

April 25, at 10 h. and 11½ h. little less than, Cephei, and considerably brighter than γ Lacertæ.

April 26, at 10 h. and 11 h. less than γ Lacertæ, something brighter than ϵ , and brighter than ξ Cephei.

May 4, at 9½ h. and 12 h. a little less than ϵ and ξ Cephei.

May 7, at 12 h. less than, Cephei, and a little brighter than γ Lacertæ.

May 9, at 11 h. a little less than ϵ Cephei.

May 10, at 12 h. between γ Lacertæ and ϵ Cephei, but something nearer ϵ .

May 11, at 10 h. and 12 h. brighter than, Cephei, less than ζ Cephei, and much brighter than γ Lacertæ.

May 14, at 11½ h. much less than γ Lacertæ, equal to, if not a little brighter than, ϵ Cephei, and brighter than ξ Cephei.

May 15, at 9½ h. less than ϵ , and about equal to ξ Cephei.

May 19, at 9½ h. and 11 h. equal to, if not a little brighter than, ϵ Cephei, and brighter than ξ Cephei.

May 20, at 9½ h. 11 h. and 12 h. a little less than ϵ , and nearly equal to ξ Cephei.

May 21, at 12 h. equal to, if not a little less than, Cephei; less than ζ Cephei, and considerably brighter than γ Lacertæ.

May 22, at 10 h. and 11½ h. a little brighter than, Cephei, the rest as last night.

May 23, at 11 h. and 11½ h. nearly equal to γ Lacertæ, and less than, Cephei.

May 25, at 10 h. and 12 h. a little less than ϵ , and about equal to ξ Cephei.

May 27, at 10 h. between ζ and ι Cephei, and considerably brighter than γ Lacertæ.

May 28, at 12 h. between ι Cephei and γ Lacertæ.

June 1, at $9\frac{1}{2}$ h. I thought it less than ι Cephei; air not clear, and twilight pretty strong.

At $10\frac{1}{2}$ h. and 12 h. between ζ and ι Cephei, but rather nearer ι .

June 2, at 12 h. exactly the same.

June 6, at 12 h. ditto; the weather was not very favourable, but the observation seemed good.

June 10, at $11\frac{1}{2}$ h. a little less than ϵ Cephei.

June 12, at 11 h. between ζ and ι Cephei.

June 21, at 10 h. nearly equal to, if not a very little brighter than, ϵ Cephei; twilight.

At $11\frac{1}{2}$ h. a little less than ϵ , and about equal to ξ Cephei.

June 23, at $11\frac{1}{2}$ h. between ζ and ι Cephei, and brighter than γ Lacertæ.

June 24, at $11\frac{1}{2}$ h. ditto; only a short view.

June 25, at $11\frac{1}{2}$ h. a little, but certainly, brighter than ϵ Cephei, brighter than ξ Cephei, and considerably less than γ Lacertæ.

June 26, at $11\frac{1}{2}$ h. a little less than ϵ Cephei, and equal to, if not a little brighter than, ξ Cephei.

In the above collection I find only two or three mistakes of any consequence, viz. the dates of the observations of April 7, and 8, are marked in my journal for April 8, and 9; but I have corrected them, being convinced they are erroneous: and the observation of May 10, I think, disagrees rather too much from what it ought to be by computation.

The following observations were made by my friend Mr. E. PIGOTT; who, at my request, was so kind as to observe the star as often as possible, though then in an ill state of health. They are, I presume, sufficient to corroborate the variation of the star as above stated, although in one or two places there may be found some little differences between our observations.

MR. PIGOTT'S OBSERVATIONS.

1784, Oct. 25, at 12 h. rather brighter than γ Lacertæ; much brighter than ϵ Cephei, and much less than ζ Cephei; nearly between ζ Cephei and γ Lacertæ.

Oct. 26, at 12 h. seemed the same as yesterday.

Nov. 1, at 12 h. brighter than ϵ Cephei; seemed rather less than γ Lacertæ.

Nov. 13, at $8\frac{1}{2}$ h. rather, but very little, brighter than ϵ Cephei; less than γ Lacertæ.

Nov. 15, at 12 h. seemed rather brighter than γ Lacertæ, and less than ζ Cephei.

Nov. 17, at 8 h. less than γ Lacertæ; rather brighter than ϵ Cephei.

Nov. 18, at 12 h. equal to ϵ Cephei, though sometimes it seemed less; less than γ Lacertæ.

Nov. 19, at 12 h. seemed equal to ϵ Cephei.

Nov. 20, at 11 h. rather less than ζ Cephei; brighter than γ Lacertæ.

Nov. 25, at $11\frac{1}{2}$ h. if not equal rather brighter than γ Lacertæ; much brighter than ϵ Cephei.

Nov. 29, at 8 h. equal to ϵ Cephei.

Nov. 30, at $11\frac{3}{4}$ h. brighter than ϵ Cephei; less than γ Lacertæ.

At $18\frac{1}{2}$ h. much increased; rather less than ζ Cephei.

Dec. 4, at $6\frac{1}{2}$ h. sometimes thought it less, and at other times brighter, than ϵ Cephei.

Dec. 11, at $5\frac{3}{4}$ h. less than γ Lacertæ; rather brighter than ϵ Cephei.

At $11\frac{1}{2}$ h. rather brighter than γ Lacertæ; not at its full brightness.

Dec. 21, at 7 h. if any difference less than ϵ Cephei.

At $18\frac{1}{4}$ h. a little brighter than ϵ Cephei.

Dec. 22, at 8 h. less than ζ Cephei; a little brighter than γ Lacertæ.

Dec. 28, at $5\frac{3}{4}$ h. nearly equal to ζ Cephei; had only a short view of them.

1785, April 26, at $11\frac{1}{2}$ h. less than ζ , rather less than ι Cephei, brighter than ϵ Cephei, and if any difference rather brighter than γ Lacertæ.

May 4, at $9\frac{3}{4}$ h. much less than ζ Cephei, less than ι Cephei, and than γ Lacertæ, and rather brighter than ϵ Cephei.

May 7, at 11 h. rather less than ι Cephei, and brighter than ϵ Cephei.

May 9, at $11\frac{1}{4}$ h. rather brighter than ϵ Cephei, and much less than ι Cephei, and γ Lacertæ.

May 11, at $10\frac{1}{2}$ h. rather less than ζ , and rather brighter than ι Cephei; much brighter than γ Lacertæ.

May 19, at 10 h. equal to ϵ Cephei, but if any difference rather brighter; little hazy and moon-light. The same at 12 h. but the weather was not hazy then.

May 20, at $11\frac{1}{4}$ h. and $12\frac{1}{4}$ h. rather brighter than ϵ Cephei, and much less than γ Lacertæ; moon-light strong at $11\frac{1}{4}$ h.

May 21, at $12\frac{1}{4}$ h. equal to γ Lacertæ; less than ι Cephei.

May

May 22, at 12 $\frac{1}{2}$ h. equal to, if not brighter than, 7 Lacertæ; think it brighter than, 1 Cephei.

May 23, at 11 $\frac{1}{2}$ h. seemed sometimes equal to, though generally less than, 1 Cephei and 7 Lacertæ.

Having now delivered the observations, from whence I have deduced the preceding conclusions, nothing more relative to this subject remains to be mentioned, except the determination of the period; in the doing of which I must follow nearly the same methods as have been used in some preceding papers. It is very evident, from a rough calculation, where only single periods or very short intervals are used, that it is about five days and eight hours. In order to determine this period with greater exactness, I have, in the following table, collated some of the most precise phases. The first five are times when 1 Cephei was observed to be equal to 7 Lacertæ during the course of its increase of brightness, which proceeds rapidly. The five next are similar times, with this only difference, that as it was not then actually observed to be equal to 7 Lacertæ, a proper allowance from the nearest observations was made on supposition that the changes are similar in every period. The ten last are assumed times between its least and greatest brightness, which determinations can hardly err more than a few hours, as the whole increase is completed in thirteen hours; but even were it so, the periods deduced from them would still be exact, because the intervals are very long.

1784 and 1785.

D.	H.		D. H. M.
Nov. 25,	$8\frac{3}{4}$	} an interval of 14 periods each of	5 8 34+
Feb. 8,	9		
Dec. 11,	$6\frac{3}{4}$	ditto	5 8 54 $\frac{1}{2}$
Feb. 8,	9		
Nov. 25,	$8\frac{3}{4}$	ditto	5 8 36
April 8,	8		
Nov. 30,	16	ditto	5 8 40
April 8,	8		
Nov. 30,	16	ditto	5 8 35 $\frac{1}{2}$ -
April 24,	8		
Oct. 23,	21	ditto	5 8 41 $\frac{1}{2}$ +
May 21,	0		
Nov. 19,	22	ditto	5 8 31 $\frac{3}{4}$
May 21,	0		
Dec. 22,	1	ditto	5 8 32 +
May 21,	0		
Nov. 19,	22	ditto	5 8 40 $\frac{3}{4}$
April 2,	23		
Nov. 19,	22	ditto	5 8 30
Dec. 22,	1		

Hence the period is, on a mean,

5 8 37 $\frac{1}{2}$ +

A few cursory remarks shall conclude this Paper. What I have before mentioned, that the greatest brightness of δ Cephei does not seem to be always quite the same, is not peculiar to this star, but is also to be observed in the other variable ones. I have remarked in a late Paper, that the greatest brightness of β Lyræ is subject to considerable alterations, and thought then that it might be owing to some fallacy of observation; but now

I have reason to alter, in some measure, my opinion on this head. Even Algol does not seem to be always obscured in the same degree, being perceived to be sometimes a little brighter than ρ Persei, and sometimes less than it *. These seeming irregularities, however, do not appear to affect the period; for if we compare the same precise phases together, it will be found still regular. This may, I suppose, be accounted for, by a rotation of the star on its axis, having fixed spots that vary only in their size.

I need not say, that the situation of δ Cephei, on account of its great northern declination is such, that its changes may be observed with great advantage in these latitudes, it being always sufficiently elevated above the horizon. To this circumstance are also owing its various changes of position, which, I find, affect the comparative brightness of the stars a little; but, as these differences are very trifling, I shall take no further notice of them.

If you think this account worthy of notice, I beg you will be so kind as to communicate it to the Royal Society.

I remain, with great regard, &c.

JOHN GOODRICK.

* This will appear from an attentive examination of the observations of that star's diminution in my two late Papers, which were printed in the LXXIII^d and LXXIVth volumes of the Philosophical Transactions. I did not take much notice of it then, because I thought the difference was too small to be relied on; but the observations I have made since seem to confirm that it does *really* diminish a little unequally. M. MECHAIN, in a letter to MR. E. PIGOTT, mentions the same fact.

